Selective Manipulation of Nanoparticles in Very Large Scale Integration (VLSI) using Magnetotactic Bacteria

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Abstract

Magnetotactic bacteria are a group of prokaryotic cells that orient and migrate along the geomagnetic field lines for their physiological functions and anaerobic/microaerophilic requirements. We report the use of magnetotaxis i.e. sensitivity towadrs megnetic field of *Magnetospirillum magneticum* as a functional component in very large scale integration (VLSI) design and fabrication. It is known that magnetotaxis arises out of a chain of magnetic nanoparticles within the bacterial cell that acts as a dipole. We propose a simple MATLAB based analysis and modeling of magnetic field acting on the chain of nanoparticles around a current carrying microwire. COMSOL was used to design the appropriate solenoid mesh containing the microwires. Our simulation results show that it is possible to manipulate the bacteria as "skilled workers" to transport select nanoparticles conducive to microchip fabrication. The use of magnetotactic bacteria may lead to the design of biomolecule based transformative integrated circuits well below the current feature size.

Key Research Components

a. Magnetic field around a current carrying conductor.
b. Force exerted by a current carrying conductor.
c. Heat dissipation around a current carrying conductor.
d. Controller controlling the current through the conductor.
e. Binding capabilities of the flagellum to the inorganic molecules.

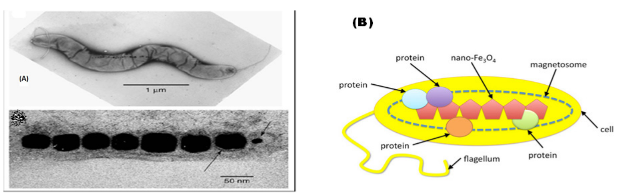

Figure 1. *Magnetospirillum magneticum*: (A) TEM Image (B) Schematic showing the magnetosomes

Conductor Mesh Modeling

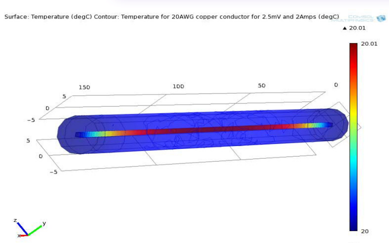

Figure 2. Heat Dissipation for 15cm 20AWG conductor

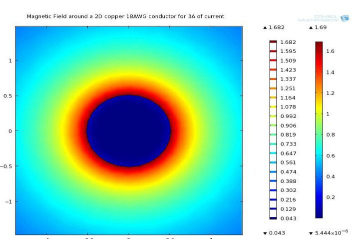

Figure 3. Magnetic Field Around a Current-Carrying Conductor

MATLAB analysis shows the complex relationship between magnetic field intensity (B), Radial distance from the surface of the conductor (R) and Current flowing through the conductor (I). It is found that as the radial distance increases, the magnetic field intensity would decrease. Also the magnetic field intensity is directly proportional to the current but there is a trade-off between the magnetic field intensity and the heat dissipation from the surface of the conductor for which COMSOL is used to model the heat flow.

$B = (\mu_0 * N * I)/L$

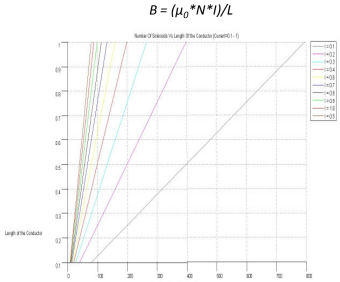

Figure 3. Relation between N, I and L for a solenoid producing 1G of magnetic field.

$B = \mu_0 I/2\pi R$

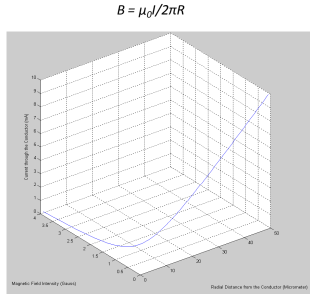

Figure 4. 3-D graph showing relation between B, R & I

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Controller Modeling

a. Use of finite state machine involving five states for the placement of each microbead.
b. Three counters & one master counter governing the assertion of entire state machine.
c. Five states namely 'Reset', 'Chamber Selection', 'Mesh Wire Selection', 'Micro-bead Placement' & 'Current Reversal'.
d. Consists of four steps in total for the component fabrication.

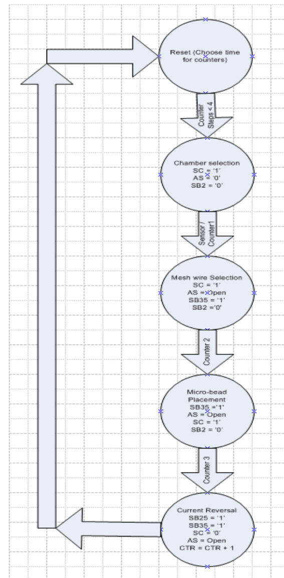

Figure 5. Finite State Machine (Controller)

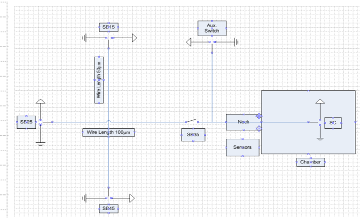

Figure 6. System Concept

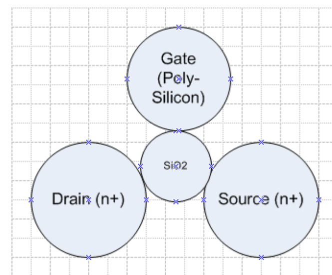

Figure 7. Expected Device (NMOS)

Controller Simulation

A three state controller is initially designed using VHDL in Quartus-II and is tested for functional verification. Initially pre-calculated 32 clock cycles are used to set the counters and the results obtained are satisfactory. This preliminary design gives an approximate position of the switches (transistors) involved in the control of the current through the solenoid mesh. Figure 8 shows the RTL view of the gate-level schematic in Quartus-II and figure 9 shows the timing waveforms .

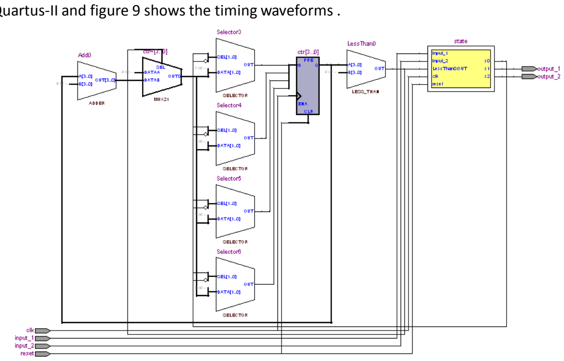

Figure 8. RTL view of the gate-level schematic for the controller

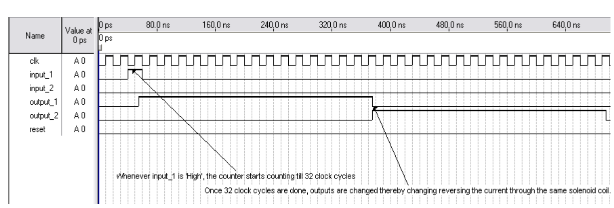

Figure 9. Controller Simulation using VHDL in Quartus-II.

Conclusion & Future Work

This research work mainly focuses on the design and fabrication of integrated circuits (VLSI chips) beyond 16nm below which traditional fabrication techniques involving UV light seem to be unpractical due to the limit on the wavelength of light. We have successfully done the modeling of the conductor mesh using MATLAB & COMSOL. Analysis of heat dissipation using COMSOL gave enough information to set the size of conductors in the mesh so as to produce enough magnetic field with a little rise in the temperature. Another area to look into is MEMS for the fabrication of the chamber in which the bacteria resides. Experiments using on-board FPGA or ASIC chips, bacterial motion under increasing temperature over the micro-wire (straight & solenoid) as well as flagella binding will be conducted in the future to confirm the proposed approach.